



# Overview of Clinical Hyperbaric Medicine

Davis Hyperbaric Laboratory, Brooks AFB, TX



## **An Overview of Clinical Hyperbaric Medicine**

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### **HYPERBARIC OXYGEN (HBO)**



Treatment with 100% oxygen inhaled in  
a pressurized environment or chamber

DAVIS HYPERBARIC LABORATORY  
Brooks AFB, TX

[HTTP://WWW.BROOKS.AF.MIL/WEB/HYPER](http://www.brooks.af.mil/web/hyper)



- The Clerics Of Hyperbarics
- The Gurus Of Gas
- The Sultans Of Squeeze
- The Omnipotent Oxygenators
- Masters Of The Vertical Continuum





## **Clinical Hyperbaric Medicine**

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- ◆ 1920's Cunningham
- ◆ 1967 Undersea Medical Society
- ◆ 1975 over 125 indications for HBO
- ◆ 1976 UMS---Committee on Hyperbaric  
Oxygenation (every 3 years)  
---12 “approved” indications
- ◆ 1986 Undersea & Hyperbaric Medical  
Society (UHMS)
- ◆ 1996 13 “approved” indications



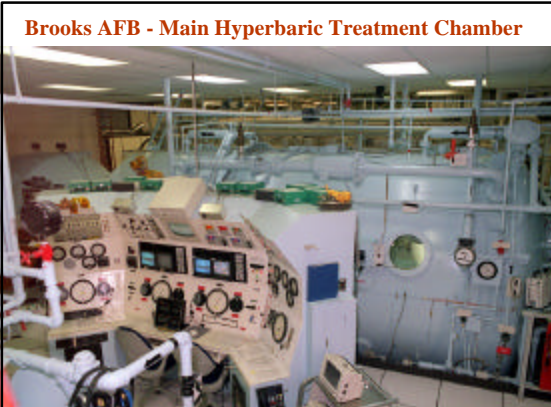
**NATIONAL ENQUIRER** 65¢  
World Exclusive Photos  
**Sensational Media Snake Oil**  
Michael Jackson's Bizarre Plan to Live to 15



## **“Approved” Indications**

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- ◆ primary treatment modality
  - DCS
  - AGE
  - Acute CO Poisoning
- ◆ adjunctive treatment modality
  - acute thermal burns
  - compromised skin grafts/flaps
  - crush injury/other acute ischemias



**Brooks AFB - Main Hyperbaric Treatment Chamber**

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### “Approved” Indications

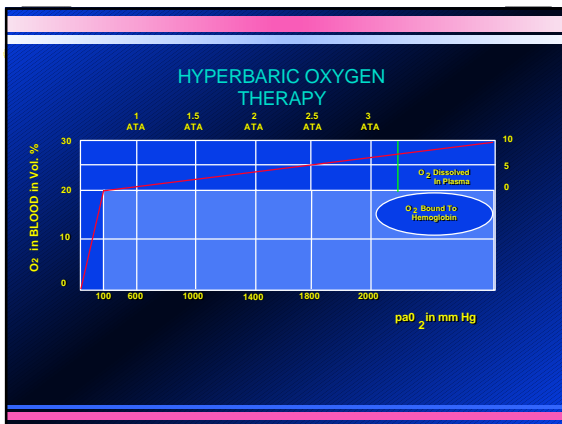
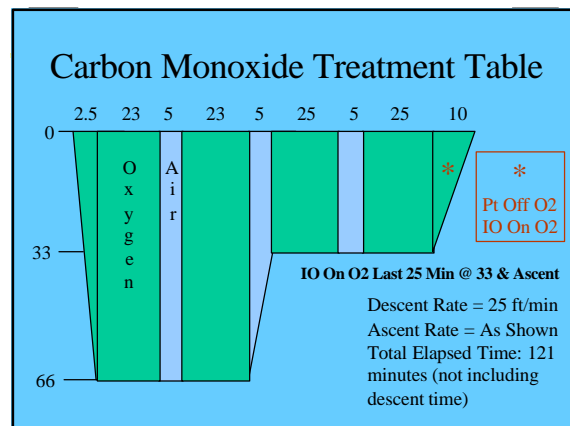
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- ◆ adjunctive treatment modality (cont.)
  - selected problem wounds
    - vascular insufficiency
    - diabetic ulcers
  - clostridial gas gangrene
  - necrotizing soft tissue infections
  - osteoradionecrosis
    - soft tissue radionecrosis
  - refractory chronic osteomyelitis
  - intracranial abscess
  - exceptional blood loss anemia

### Carbon Monoxide Rules

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- Treat All With Any Hx CNS Symptoms (other than mild H/A only) Regardless Of CO-Hgb Level
- May Extend To A Maximum of 6, 25 min O2 Periods @ 33 FSW
- Extend Based on Clinical Assessment
- Inside Observer Takes 25 min O2 during last O2 period at 30 FSW, and 10 min during ascent to Surface. Any Ext @ 30 FSW - add 10 min O2 for each extension.
- Tailing Dives @ 45 FSW may be needed in severe cases
  - 3, 30 min O2 periods w/ 10 min air breaks
- Monoplace Chambers Must Use BIBS for Air Breaks



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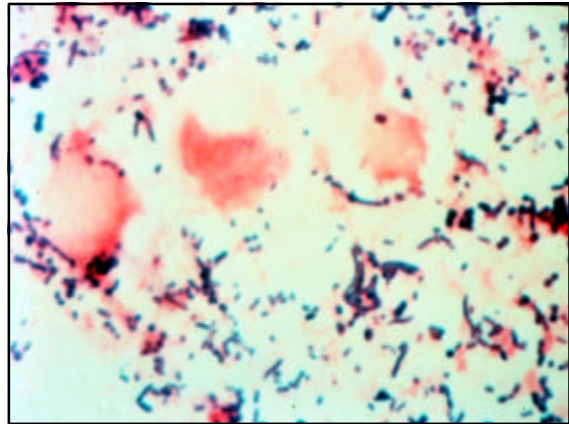




## **GAS GANGRENE**

**--Clostridial Myonecrosis**

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- ◆ RAPIDLY PROGRESSIVE
- ◆ MUSCLE NECROSIS
- ◆ ETIOLOGY: Clostridial organisms
- ◆ LOCAL AND SYSTEMIC SYMPTOMS
- ◆ MINIMAL HOST RESPONSE





## **ALPHA TOXIN**

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- ◆ FACILITATES A RAPIDLY SPREADING LIQUEFACTION NECROSIS
- ◆ PROGRESSIVE NATURE DEPENDS ON CONTINUOUS TOXIN PRODUCTION
- ◆ TOXIN IS NOT PRODUCED IF OXYGEN TENSION IS **> 250mm Hg**



## **TREATMENT**

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- ◆ SURGERY\*\*\*
- ◆ ANTIBIOTICS
- ◆ HYPERBARIC OXYGEN THERAPY



## **TREATMENT RESULTS**

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<b>HBO SURVIVAL RATE</b>	<b>70-80%</b>
<b>NON-HBO SURVIVAL RATE</b>	<b>40-50%</b>



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## Selected Problem Wounds

\*\*\* WOUND HEALING \*\*\*

- ◆ **vascular phase**
  - 5-10 minutes leaky vessels
- ◆ **inflammatory phase**
  - 1-3 days WBC's: polys then monos then macrophages
- ◆ **migratory phase**
  - day 4 macros stimulate for fibroblasts that migrate
- ◆ **proliferative phase**
  - 5-14 days collagen deposition and angiogenesis
- ◆ **maturation phase**
  - up to 2 years laminar collagen at 75-85% normal strength




## Diabetes Mellitus

- ◆ 5% of population (12+ million)
- ◆ 50% are admitted with foot problems
- ◆ 50 - 70% of all amputations

**huge economic and social drain on the health care system**






## Diabetes Mellitus

- ◆ prospective controlled study
- ◆ grade 3 & 4 wounds (3 = deep tissue; 4 = gangrene)

	<u>HBO</u>	<u>Control</u>
patients	18	10
restored	16 (89%)	1 (no change in 5)
amputation	2 (11%)	4 (40%)

---Baroni et al



## Diabetes Mellitus

- ◆ matched groups

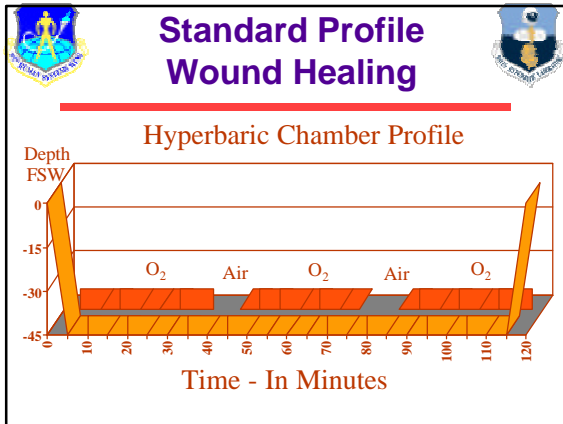
	<u>HBO</u>	<u>Control</u>
patients	62	18
restored	59 (96%)	12 (67%)
amputation	3 (5%)	6 (33%) (39% historic)

---Oriani et al



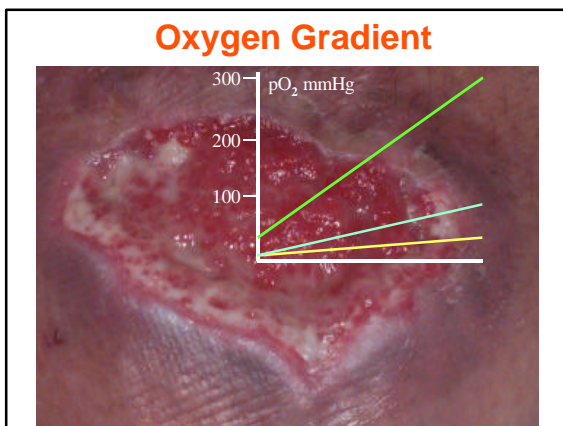
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## Important Healing Facts

- ◆ There **must** be a steep hypoxic gradient
- ◆ Leukocyte **requires** 30 mmHg oxygen tension
- ◆ Fibroblast **requires** 30 mmHg oxygen tension



## Transcutaneous Oxygen Measurement

- ◆ noninvasive
- ◆ localized measure of tissue oxygen tension
- ◆ indirect measure of overall tissue perfusion
- ◆ results:
  - > 30 mmHg in nondiabetic desirable
  - > 40 mmHg in diabetic desirable
  - on 100% oxygen (1 ATA) want > 100 mmHg (maybe 150!)

## Venous Stasis

- ◆ 16 patients in double-blinded controlled study
  - no chronic disease
  - no large vessel disease
  - no smoking
  - wound present > 1 year without recent change
- 30 treatments
- HBO group had a significant decrease in wound area
  - 4 weeks = 20% decrease in area
  - 6 weeks = 40% decrease in area


---Hammarlund et al




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## Radiation Tissue Damage



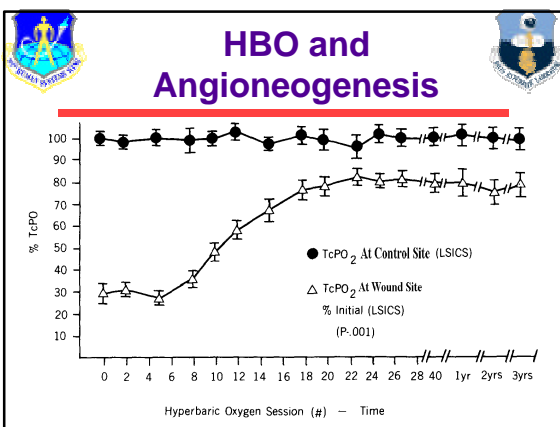
- ◆ source: external irradiation and brachytherapy
- ◆ rapidly dividing cells are most susceptible
- ◆ endothelial cells
  - progressive obliterative vasculitis
  - 3-H tissue (hypovascular, hypoxic, hypocellular)
- ◆ chronic result is a tissue that is unable to generate a steep hypoxic gradient




## Mandibular Osteoradionecrosis




- ◆ prototypic radiation tissue damage
- ◆ prior to HBO use: surgery + antibiotics
  - 92% failure rate
- ◆ Marx---animal and human studies
  - 8 - 10 Rx's = lag phase
  - 11 - 22 Rx's = rapid rise phase
  - 23 - 30 Rx's = plateau phase





## Mandibular Osteoradionecrosis





- ◆ HBO results in angiogenesis
  - 75 - 85% of normal vasculature
- ◆ HBO + surgery +/- antibiotics
  - 92% success rate
- ◆ NIH Consensus Statement
  - HBO is "standard of care"
- ◆ HBO prophylaxis is very useful for tooth extraction s/p radiation

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## Other Radiation Tissue Injuries

- ◆ cystitis
- ◆ proctitis
- ◆ obstruction
- ◆ fistula
- ◆ soft tissue breakdown
  - chest wall
  - pelvis

**consider pre-op HBO for surgery in an irradiated field**



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### Chronic Refractory Osteomyelitis

- ◆ Cierny-Mader Classification
  - Anatomic Stage
    - Stage I = medullary
    - Stage II = superficial
    - Stage III = localized\*
    - Stage IV = diffuse\*
  - Physiologic Stage
    - A host = normal host
    - B host = systemic compromise (Bs)  
local compromise (BI)
    - C host = treatment worse than disease

### Compromised Host (B)

Systemic	Local
◆ malnutrition	◆ venous stasis
◆ renal/liver failure	◆ major vessel compromise
◆ chronic hypoxia	◆ arteritis
◆ immune deficiency	◆ extensive scarring
◆ malignancy	◆ radiation fibrosis
◆ diabetes mellitus	◆ small vessel disease
◆ age extremes	◆ loss of local sensation
◆ autoimmune disease	◆ chronic lymphedema
◆ tobacco/Etoh abuse	

### Osteomyelitis Incidence

- ◆ trauma
  - closed fracture < 1%
  - open fracture, no crush 5%
  - crush > 30%
- ◆ surgery
  - elective surgery < 1%
  - emergent surgery > 30%

### Characteristics of Osteomyelitis

- ◆ common sites
  - tibia, femur, fibula, mandible, phalanx, calcaneus
- ◆ bacteria
 

● aerobic	Gm +: Staph aureus	40-60%
	Staph epi	1-10%
	Gm -: E. coli, Kleb, Enter	1-10%
● anaerobic	Gm +: Peptostrep, Clostr sp	1-10%
	Gm -: Psuedo, Prot, Serratia	10-20%
● mixed	Staph, Psuedo, Entero, Serr, E. coli	10-20%



### Oxygen Tension within Bone

- ◆ normal bone
  - on Room Air > 40 mmHg
  - at 2 ATA O<sub>2</sub> > 300 mmHg
- ◆ osteomyelitic bone
  - on Room Air < 23 mmHg
  - at 2 ATA O<sub>2</sub> > 100 mmHg





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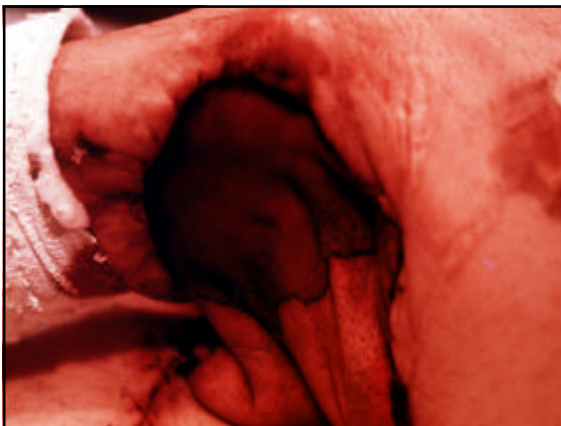
## Osteomyelitis

- ◆ diagnosis
  - bone scan, MRI
- ◆ treatment
  - antibiotics (HBO synergy)
  - surgery
  - HBO
    - 2.4 ATA for 90 minutes x 30-45 treatments
- ◆ triple regimen for chronic refractory cases
  - 60 - 85% success rate




## Compromised Skin Grafts and Flaps

- ◆ HBO
  - decreases ischemia
  - decreases edema
  - improves fibroblast function
  - improves leukocyte function
  - decreases reperfusion injury




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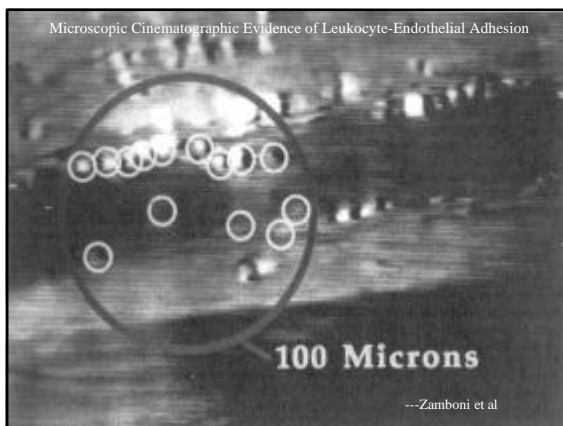
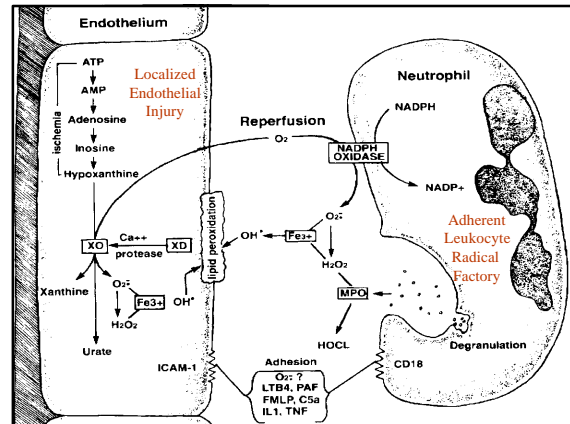
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## Reperfusion Injury




- ◆ after period of ischemia find an accumulation of anaerobic products (ie, hypoxanthine)
- ◆ with reperfusion, there is a short burst of free radical release causing a localized injury
  - hypoxanthine becomes xanthine with oxygen
- ◆ localized injury brings in leukocytes that adhere to endothelium becoming free radical factories causing extensive damage







## Evidence



- ◆ **Animals**
  - Nemiroff: increased vessel number  
increased vessel size
  - Manson: 3x growth in distal capillaries (pig flaps)
- ◆ **Humans**
  - Perrins: -- 48 patients with STSG
    - no HBO 17% with full graft take
    - HBO 64% with full graft take
  - Bowersox: -- 104 patients treated with HBO
    - threatened-flap salvage 89%
    - threatened-STSG salvage 91%



## Crush Injury Compartment Syndrome



### Other Acute Traumatic Ischemias

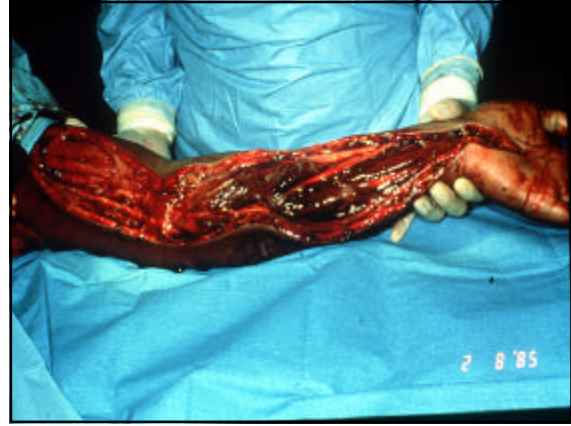
CHARACTERISTICS



- ◆ **primary**
  - hypoxia/ischemia\*, edema\*, injury gradient, reperfusion injury
- ◆ **secondary**
  - microcirculation stasis\*, contracture formation, infection, compromised wound healing



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## Edema is a Killer

- ◆ increases the required diffusion distance resulting in hypoxia
- ◆ increases the interstitial tissue pressure exceeding the capillary perfusion pressure
  - capillary bed collapse
  - microcirculatory stasis

\*\*\* edema begets ischemia begets edema \*\*\*



## HBO Effects

- ◆ hyperoxygenation
- ◆ vasoconstriction
- ◆ improved fibroblast function
- ◆ improved leukocyte function
- ◆ reduced reperfusion injury



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## Evidence

- ◆ randomized, double-blinded, controlled trial
- ◆ 36 patients (blunt trauma)
- ◆ 2.5 ATA x 90 minutes BID for 6 days

	<u>HBO</u>	<u>non-HBO</u>
comp. healing	17/18	10/18*
new surgeries	1/18	6/18*
healing (>40)	7/8	3/10*
healing (<40)	6/6	1/1
amputations	0/18	2/18
skin flaps/grafts	1/18	6/18

---Bouachour et al



## Thermal Injury




- ◆ 1965 Wada et al
    - Japanese coal mine disaster
    - HBO for inhalation/CO injury
    - noted improved healing of partial thickness burns
  - ◆ burns
    - zone of coagulation (death)
    - zone of stasis (ischemia)
    - zone of erythema (inflammation)
- in first 48 hrs can see 10X expansion of injury**





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### Burn Healing and Scarring

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<u>time to healing</u>	<u>hypertrophic scar</u>
< 10 days	4%
10 - 14 days	14%
15 - 21 days	28%
> 21 days	40%

### Evidence

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- ♦ animals
  - Sanders no HBO 13/15
    - no subdermal perfusion
  - HBO 13/15
    - positive subdermal perfusion
- ♦ Clark survey (1995)
  - 133 responding centers
  - 32% used HBO regularly

### Evidence

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- ♦ humans
  - Hart randomized, double-blind, controlled trial
    - 2 ATA for 90 minutes = first 24 hrs---every 8 hrs
    - after 24 hrs---every 12 hrs
  - 10 - 14 days of treatment
  - decreased fluid requirements
  - improved healing speed
  - reduced mortality



### Evidence

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- ♦ humans
  - Merola 37 pts HBO vs 37 pts no HBO
    - improved healing speed
  - Nju 266 pts HBO vs 609 pts no HBO
    - reduced infections
    - reduced mortality
  - Cianci
 

	<u>HBO</u>	<u>control</u>
• 18 - 39% TBSA	LOS 21 days	33 days
• 40 - 80% TBSA	surg. 3.7	8.0



    - overall trends: decreased LOS, decreased surgeries, reduced cost

### Exceptional Blood Loss Anemia

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- ♦ oxygen carrying capacity resides with RBC
- ♦ RBC mass carries 20+ vol % oxygen
- ♦ daily living extracts about 6 vol %
- ♦ plasma can carry about 6 vol %
- ♦ > 40% blood loss requires transfusion
- ♦ NO transfusion
  - Jehovah's Witness faith
  - cross-match incompatibility (ie, hemophilia)

### Exceptional Blood Loss Anemia


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- ♦ Boerema (1960)
  - “Life without Blood”
  - piglets without RBC lived nicely at 3 ATA
- ♦ Hart (1987)
  - 26 patients (22 Jehovah's Witness)
  - mean hematocrit 12.9%
    - survivor hct 13.7% ---10 days Rx
    - fatality hct 10.5% --- 3 days Rx




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### Hart Treatment

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- ◆ volume expanders
- ◆ lower extremity wraps
- ◆ chamber criteria
  - heart rate > 125/min
  - blood pressure < 90 mmHg or vasopressors
  - altered sensorium
- ◆ HBO---monoplace or multiplace\*\*




### Hart Treatment

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- ◆ parameters using HBO
  - heart rate slowing to < 100
  - blood pressure rising to > 100/40
  - sensorium clearing
- ◆ discontinue HBO
  - hct 23%    hgb 7.7                      retic 8.4%
- ◆ complications---ear barotrauma (50%)
- ◆ results:    **18 survived**                      **8 died**
  - 6 were decerebrate/decoricate prior to treatment




### Intracranial Abscess

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cerebral abscess, subdural empyema,  
epidural empyema

- ◆ average mortality is 17.3%
- ◆ patient with a severe problem
  - multiple abscesses                      deep/dominant abscesses
  - compromised host                      no response to therapy
- ◆ HBO
  - 2.5 ATA for 90 minutes
  - average of 12 treatments




### Intracranial Abscess

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- ◆ HBO results
  - Lampl et al:        14 cases --- all survived
  - case reports:        6 cases --- all survived
- ◆ all cases to be reported to UHMS
  - to fully document effectiveness





### Cutaneous Loxoscelism

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- ◆ majority of bites (90%)
  - unnoticed or mild stinging
  - if no effect within 48-96 hrs; expect no necrosis
- ◆ minority of bites (10%)
  - symptoms usually within 10 minutes!!!


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### Cutaneous Loxoscelism




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- 4-7 days: vesicle rupture with formation of necrotic crust/eschar
- 7-14 days: central eschar mummification  
eschar sinking  
intermittent slough of eschar  
ulcer--25-30 cm
- 1-6 months: eventual healing  
excessive scarring



### Treatment


#### Cutaneous Loxoscelism



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Hyperbaric Oxygen Therapy (HBO)

- ◆ oxygenates ischemic tissue
- ◆ maximizes leukocyte function
- ◆ maximizes fibroblast function
- ◆ inactivates venom (?)
- ◆ inactivates venom cascade (?)
  - a modified “reperfusion” phenomenon



### Treatment

#### Cutaneous Loxoscelism




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HBO


- ◆ **evidence conflicting (human)**
  - pro: Svendsen (1986)
    - 15 cases: 2 ATA x 90 min bid for 3-6 Rx's
    - no surgery, painfree at 48 hrs, minimal slough
    - healed within 1 month
    - ?? sulfhydryl group disruption inactivation
    - Maynor--rabbit; no effect on Sphing D
    - Merchant--10 ATA x 12 hrs *in vitro*
    - no effect *in vivo*





### HBO Contraindications

#### Untreated Pneumothorax




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◆ viral infection/URI	◆ disulfiram
◆ COPD	◆ insulin
◆ hx of spon. pneumo.	◆ ointments/creams
◆ hx of chest surgery	◆ steroids
◆ narcotics	◆ cis-platinum
◆ Etoh	◆ doxorubicin
◆ nicotine	◆ bleomycin
◆ nitroprusside	◆ fever
◆ sulfamylon	◆ acidosis


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### Contraindications

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- ◆ diamox
- ◆ hereditary spherocytosis
- ◆ malignant tumors
- ◆ pregnancy
- ◆ hx of ear surgery
- ◆ claustrophobia
- ◆ seizure disorder
- ◆ hx of seizure disorder
- ◆ ear/sinus congestion
- ◆ no code status
- ◆ obesity



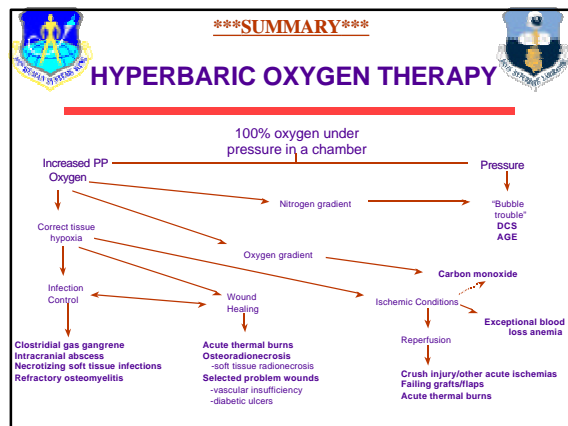


### Complications

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- ◆ barotrauma --- ears, sinuses, teeth
- ◆ transient myopia
- ◆ hypoglycemia
- ◆ CNS toxicity
- ◆ unexpected GI gas expansion
- ◆ ulnar paresthesias
- ◆ pulmonary overpressure syndrome (POPS)



### HYPERBARIC MEDICINE DIVISION

#### DAVIS HYPERBARIC LABORATORY

#### USAF SCHOOL of AEROSPACE MEDICINE

#### BROOKS AFB, TEXAS

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DSN 240-3281 COMM (210) 536-3281

**24- HOUR PHONE:**

DSN 240-3278 COMM (210) 536-3278

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